
Shower Studies at around 10^{18} eV with the Surface Detector of the Pierre Auger Observatory

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Abstract

Three months of data taken by the Engineering Array Surface Detector of the Pierre Auger Observatory have been analyzed with the aim of setting a procedure for the study of showers at $E_0 \approx 10^{18}$ eV. We present the results, concerning: (i) the selection procedure and the check of its efficiency; (ii) the event rate and its stability; (iii) the characteristics of such events (i.e., angular direction, energy estimator $S(1000)$, rise time vs core distance, correlation with pressure) showing their consistency with the expectations. The performances of the whole Surface Detector of the Auger Observatory are discussed.

1. Introduction

The study of cosmic rays around 10^{18} eV with the surface detector of the Auger Observatory will be of main significance for: a) the verification and extension of the CR anisotropy measurement reported by AGASA [1], SUGAR [2] and Fly's Eye [3] from the directions of the Galactic Center and Disk; b) the measurement of the CR flux in an energy range interconnected with other experiments; c) the possibility of improving the cross calibrations with the Auger fluorescence detector, which naturally operates at lower threshold. The Auger southern site surface detector, under construction in the province of Mendoza, Argentina, will consist of 1600 water Cherenkov detectors (WCD), on a triangular grid with a 1.5 km spacing, covering an area of about 3000 km²; a subset of it, the "Engineering Array" (EA), including 32 completely instrumented stations, has been in operation since 2002. We present here the analysis of three months of data taken between May and July 2002, to set a procedure for the selection of showers around 10^{18} eV.

2. Analysis and results

To define the most appropriate trigger configuration to select events with $E_0 \approx 10^{18}$ eV, we conducted a preliminary study, using the data from a WCD

prototype operated in correlation with AGASA ($E_0 > 10^{18}$ eV and $\theta < 45^\circ$) [4]. The analysis [5] consisted of the simulation of the Auger trigger and its application to the WCD data after proper conversion to the Auger scale. This allowed the derivation of the single tank trigger efficiency as a function of its rate, f_t , core distance, r , and energy, E_0 . The array trigger efficiency, η , obtained from such data, is shown in Tab.1 for different f_t and E_0 .

f_t [Hz]	E_0 [eV]	η_{3-fold}	η_{4-fold}
20	1-2 $\cdot 10^{18}$	0.25	0.01
20	2-4 $\cdot 10^{18}$	0.45	0.07
2	1-2 $\cdot 10^{18}$	0.23	0.01
2	2-4 $\cdot 10^{18}$	0.40	0.05

Table 1. Array trigger efficiencies for different E_0 and f_t .

f_t [Hz]	Δt [μ s]	N_{ch} (/yr)	N_{exp} (/yr)
20	25	$1.5 \cdot 10^6$	$3 \cdot 10^4$
20	5	$6 \cdot 10^4$	$3 \cdot 10^4$
2	25	$1.5 \cdot 10^3$	$2.8 \cdot 10^4$
2	5	60	$2.8 \cdot 10^4$

Table 2. Full Auger: expected events, N_{exp} , and accidental 3-fold ones, N_{ch} , for different f_t and Δt .

Due to the low efficiency of 4-fold mode, 3-fold events have to be used. The background rate due to 3-fold random coincidences for the whole Auger detector is given in Table 2 together with the rate of expected CR events, N_{exp} , with $10^{18} < E_0 < 2 \cdot 10^{18}$ eV, evaluated using the CR spectrum [6], the Auger acceptance ($A\Omega \approx 4700$ sr km², $\theta < 45^\circ$) and η .

The extraction algorithm is firstly based on the selection of 3 nearby triggered tanks in a equilateral pattern. For the Auger-EA ($f_t \approx 20$ Hz and coincidence window $\Delta t \approx 25\mu$ s) the measured rate, $N_{sel} \approx 30$ /day, is consistent with that expected from chance coincidences.

To reduce the accidental rate, we lower (through software cuts) both Δt (to 5μ s) and f_t (to 2 Hz), so that $N_{ch} \approx 1.5 \cdot 10^{-3}$ /day.

With the described selection criteria, in the period from May 1st through July 11th 2002, we extracted 487 events (416 with $\theta < 45^\circ$). Fig.1 (top) shows the daily rate ($\theta < 45^\circ$), for days of operation with duty cycle greater than 98%. The daily rate distribution is shown in fig.1 (bottom): the average is 6.3 ± 0.4 /day, the distribution being compatible ($\chi^2 = 1.5/d.f.$) with a poissonian one.

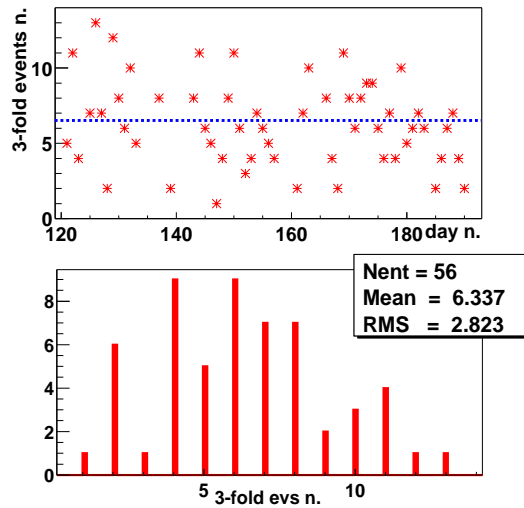


Fig. 1. 3-fold event daily rate ($\theta < 45^\circ$) vs day number (top) and its distribution (bottom).

The measured rate is then compared with the expected one due to CRs. Taking into account the contributions from different energies ($2.5 \cdot 10^{17} < E_0 < 4 \cdot 10^{18}$ eV), we evaluate it using spectrum [6], including the Auger-EA acceptance ($A\Omega \approx 51$ sr km², $\theta < 45^\circ$) and the array trigger efficiency η . η is obtained using the WCD prototype data (converted to the Auger-EA scale), in correlation with the AGASA EAS, for the different energy intervals, with an extrapolation to $E_0 < 10^{18}$ eV. The total predicted rate amounts to $N_{exp} = 5 \pm 1/\text{day}$, consistent with the measured one, within the systematic uncertainties (we remind that the results are based on trigger efficiencies evaluated at the AGASA energy scale).

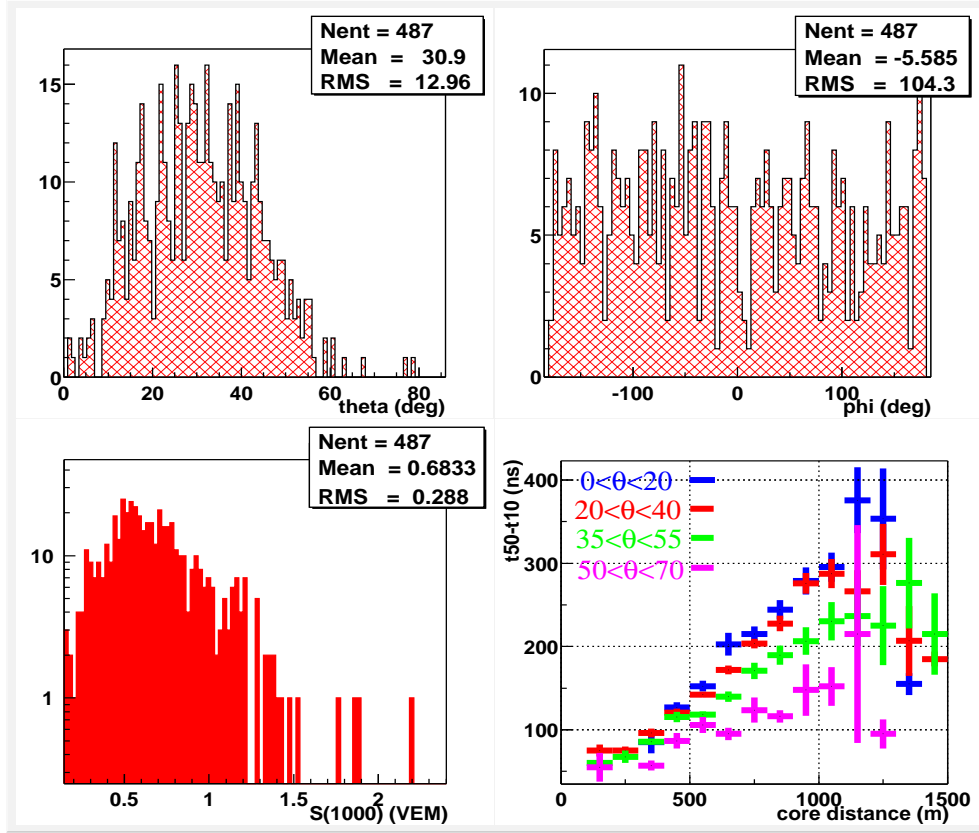


Fig. 2. Distributions of reconstructed shower parameters for the 487 selected events: zenithal angle (top left), azimuthal angle (top right), $S(1000)$ (bottom left) and rise time vs core distance (bottom right) for four different intervals of θ .

The extracted events have been reconstructed, following the prescriptions given in [7]. The distributions of the arrival angles θ and ϕ are given in fig. 2 (top left and right, respectively), showing good consistency with the expectations. The risetimes from 10% to 50% levels of the signal ($t_{50} - t_{10}$) vs core distance (r) in four intervals of θ are shown in the same figure (bottom right), being in good agreement with simulated data [8] and real ones from Haverah Park [9]. Concerning primary energy, an estimator, $S(1000)$ (i.e., the signal in Vertical Equivalent Muons at

$r = 1000\text{m}$) corrected for θ , is shown in fig. 2 (bottom left). The conversion from $S(1000)$ to primary energy is subject of intense study by the Auger Collaboration (see e.g. [7]): currently, the peak of the $S(1000)$ distribution corresponds to primary energies ranging from 0.4 to $0.9 \cdot 10^{18}$ eV (consistent with the present knowledge of the primary intensity at such energies, when compared with the measured rates). Lastly, the behavior of the event rate vs atmospheric pressure, P , has been studied. The pressure coefficient obtained is $k = 1/N(dN/dP) = -0.011 \pm 0.005 \text{ mbar}^{-1}$ (significant at 2σ), in agreement with Haverah Park [10].

3. Conclusions

Three months of data taken by the Auger-SD EA in a stable configuration have been analyzed, with the following outcome:

- an algorithm for the extraction of events around 10^{18} eV, based on geometry and single tank trigger condition corresponding to $f_t \approx 2$ Hz (to reduce the random coincidences to the percent level of the physical event rate) has been tuned and tested using a WCD prototype operated in connection with AGASA;
- the event rate is consistent with the expectations from CR showers due to primaries of energy around 10^{18} eV;
- the shower parameters (distributions of zenith and azimuthal angles, $S(1000)$, rising time vs core distance and vs zenith angle, correlation with pressure) are consistent with the expected ones;
- assuming for the full Auger-SD $\eta = 0.23$, and using the spectrum [6], we get $N_{exp}(10^{18}\text{eV} < E_0 < 2 \cdot 10^{18}\text{eV}) \approx 2.8 \cdot 10^4 \text{ ev/yr}$ (in the AGASA energy scale). The detection level of the AGASA anisotropy ($A \approx 4\%$), assuming poissonian fluctuations, would thus be $\approx 4.5 \text{ s.d./yr}$ (in harmonic analysis). Concerning stability, representing a further requirement for the measurement, within the present statistics, non poissonian daily instability effects can be verified to be $< 6\text{-}7\%$.

4. References

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